THE FORMATION OF WAVE SURFACES IN SAND.[1]

ATTENTION was first called to tidal sand ripples by Prof. Osborne Reynolds,[2] who found them submerged in channels between sand banks in estuaries. My observations were on tidal sand ripples which I found above low water (Fig. 1). They are generally unsymmetrical in form, with the steep face on the sheltered side, as are "current marks" and æolian sand ripples. They apparently do not require for their formation any co-operation between flood and ebb currents, although where such co-operation occurs, the wave fronts probably become less sinuous. They are to be seen, not only in tidal estuaries, but also in some localities on the seashore[1] where the sands are exposed to waves as well as to currents, but they face with the current, not with the waves, and are thus readily distinguished from the wave-formed ripple mark. The smallest tidal sand ripples which I have found exposed at low tide were 3 feet from crest to crest, and all sizes from this to 20 feet wave-length are common. On a sand bank in the Dovey estuary (North Wales), opposite to the town of Aberdovey, I marked out a plot with stakes driven deeply into the sand, and recorded by daily measurements the increase, diminution and march of the sand waves. At neap tides the sands were nearly smooth, and as the tides increased the tidal sand ripples appeared, short and relatively steep. The amplitude increased steadily, the average wave-length also increased, apparently by elimination of some of the ridges. When the highest spring tide was passed the amplitude rapidly diminished, the wave-length remaining nearly, but not quite, constant, and the mean sand level remaining practically unchanged. Details of the measurements will be given in the *Geographical Journal*. The circumstances favourable to the formation and preservation of tidal sand ripples above low-water mark are, gentle current at first of the flood and last of the ebb, and strong current when the water is deep over the sands. I have often watched the course of events when the last of the ebb has been running over the ridges. The process is then one of decay, not of growth, the sand being swept from the crests into the troughs. What goes on during the *growth* of the ridges? Let the depth of water be sufficient; then, if the velocity of the current be small, the sand grains roll and slide along the bottom, but, as the speed increases, the water, almost suddenly, becomes highly charged with sand in "eddying suspension." A uniform current flowing swiftly over extensive sands picks up as much sand as it drops, thus causing a drift of sand which on the whole is uniform, neither raising nor lowering the bed.[2] My observations indicate, however, that *in detail* the drift is not uniform, but attended by alternate silt and scour along lines at right angles to the current and equidistant from one another, the surface of the sand bank being thus carved into transverse ridge and furrow without change of mean level. The slightest convexity of surface causes a convergence of currents, a concavity a divergence, and, under the conditions specified, deposition occurs upon the convexities, whilst the concavities are scoured. The vertical inequalities are thus increased,[3] and it is easy to see that the ridges will extend themselves laterally.[4] Thus the ridge and furrow inevitably form and grow. What, then, are the limits of this growth? Obviously the depth of water is one limit. When the cross section of the stream above the sand ridge is reduced by a certain amount, the greater force of water there

FIG. 1.—Tidal sand ridges in the Dovey estuary. Photograph taken June 15, 1900. Wave-lengths about 15 feet.

FIG. 2.—Current mark upon tidal sand ridges. Photograph taken June 15, 1900, in the Dovey estuary.

[1] Abridged from a paper by Mr. Vaughan Cornish in the *Scottish Geographical Magazine*, January 1901.

[2] Reports of committee appointed to investigate the action of waves and currents on the beds and foreshores of estuaries by means of working models.—*British Association Reports* of meetings of 1889, 1890 and 1891.

[1] And on the Goodwin Sands, where I found them, May 12, 1900. [Since the paper was written I have seen the same structures in a non-tidal part of the Fraser River, British Columbia.]

[2] *British Association Report*, Manchester meeting (1887). Osborne Reynolds on "Certain Laws relating to the Régime of Rivers and Estuaries and on the Possibility of Experiments on a small scale."

[3] Compare G. H. Darwin's observation of the sand creeping up both sides of a ridge when a current was caused to flow over it.—*Proc. Roy. Soc.*, vol. xxxvi. 1883: "On Ripple Mark."

[4] Compare James Thompson on the "Winding of Rivers in Alluvial Plains."—*Proc. Roy. Soc.*, 1876 and 1877.

removes the sand as quickly as it is brought, and further growth is thus stopped. If the depth be further reduced, *e.g.* during an ebbing tide, the ridges decay. In deep water the height of the ridges is limited to that at which the velocity of the stream can maintain an active eddy on the lee of the ridge, and if the velocity be reduced the troughs silt up owing to the sand falling into dead water. It is probable, also, that the amplitude is sometimes restricted by the velocity of the current surpassing the limit suitable to the fineness or lightness of the material of which the ridges are composed. For it is evident that there is a difference between the pressure upon the weather side and upon the lee side of a ridge. I notice when wading on sand banks ridged with tidal sand ripples that the pressure of one's tread often causes a bodily sliding of the sand from trough to crest. The growth and even the maintenance of the ripples demands a *differential* movement of the material. There must be a part to stand fast as well as a part to be redistributed. Thus a moderate range in the sizes of the particles of the loose granular material is favourable to the formation and retention of a wavy surface through a considerable range of velocity of the inducing fluid. It is evident that two sets of crossing ridges cannot be simultaneously produced by true current action, and, in fact, crossing tidal sand ripples are seldom seen. Sometimes, when the direction of current has suddenly changed at a particular time of tide, two sets of ridges are successively formed. The "tidal sand ripples" seem, in fact, to be true current-formed sand waves. They are themselves rippled over with "current mark," which is more properly a ripple, in that (like capillary ripples) it only goes skin-deep (Fig. 2). It seems to be due rather to the pulsations of a current than to the current as such. I have often seen little sand ripples in fairly deep rapid streams, which I suppose would properly be called current mark, facing obliquely or transversely to the direction in which the sand was travelling. This was near the shore where the most marked pulsation was shorewards.

I have described elsewhere[1] some little dunes formed by the wind out of the very fine and light sand of the dry Nile bed, when the river was at its lowest. These dunes, which in size and shape somewhat resembled tidal sand ridges, were covered with a beautiful tracery of little ripples. In the formation of the æolian sand ripples the heterogeneity of the sand plays a much more important, the pulsation of the fluid a much less important, part than in the case of the current mark of streams. I have one more observation on this point to add to those already published. I noticed, during strong winds lasting several days, at Montrose, N.B., March 1900, that the rippling of the remarkably uniform dry drifting sand was very slow in beginning. As soon, however, as there was a fair supply of the coarser kind of sand grains aggregated together, the rippling action went on vigorously and rapidly. A moderate range of sizes of material, *e.g.* fine sand and coarse sand, is best for æolian rippling. In the vicinity of big stones the scour of the wind is too great. During the occasions on which I visited this little dune tract the strong breeze drifted the fine light sand thickly near the surface, and in the afternoons there was a haze of flying sand extending 20–30 feet above the foreland. The conditions were, in fact, very similar to those with which I have since become familiar in the case of formation of tidal sand ripples. It seems highly probable that the fine, light sand in this wind was in a condition similar to the "eddying suspension" of water drift, proceeding in the manner described by Osborne Reynolds, plus the rapid increase of slight inequalities forming waves, as above described. The same brisk breezes which were forming dunes as regular trains of sand waves, as high as the quantity of dry Nile sand permitted, were not able to deal in the same free fashion with the coarse quartz sand of the larger desert dunes west and east of the Delta.

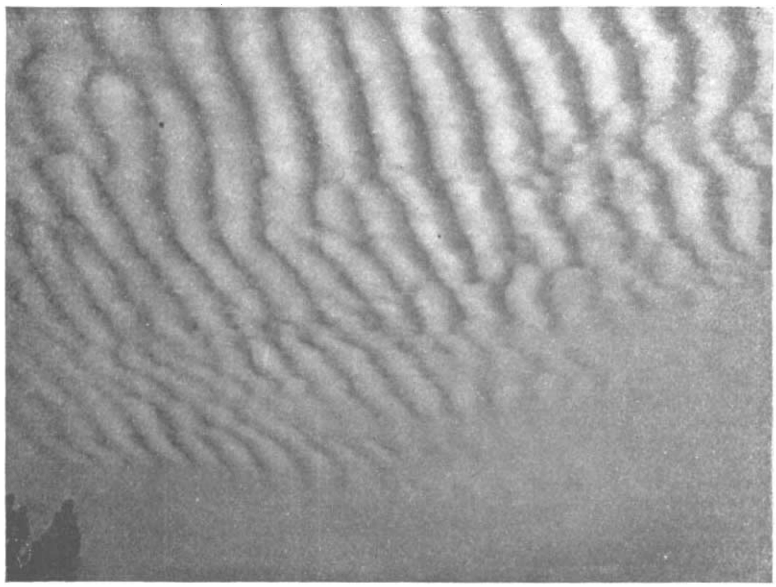

FIG. 3.—Rippled clouds. Photograph taken August 5, 1900, near Bournemouth, 5.15 p.m., looking S.

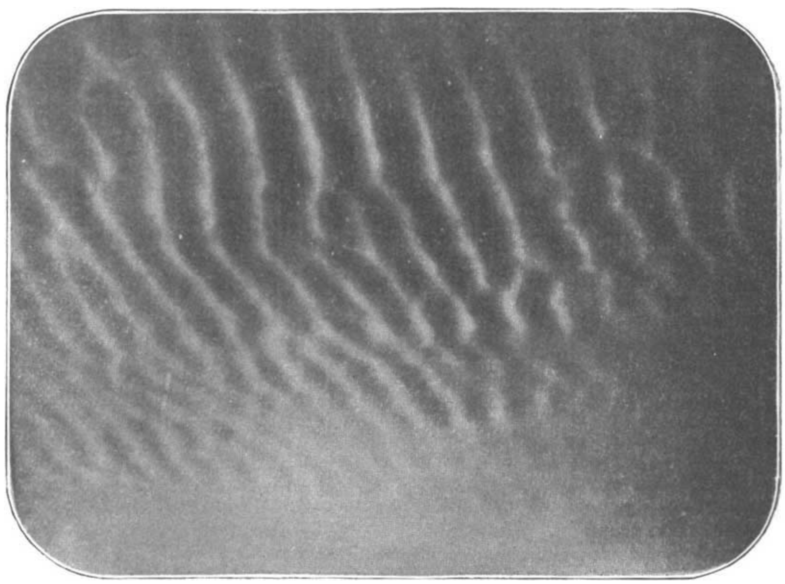

FIG. 4.—The true aërial ripple mark. This is the negative of Fig. 3, and shows the ridges of still air between the whirling air of the clouds.

[1] "On Desert Sand Dunes Bordering the Nile Delta."—*Geogr. Journ.* January 1900.

Note on Photographing Aërial Ripple Mark.

Fig. 3 is reproduced from a photograph which I took of some remarkable ripple clouds near Bournemouth, on August 5, 1900, at about 5.15 p.m. The camera was pointed south; the sun, of course, is on the right, and the shadow of each cloud can be seen on the right-hand edge of the next one. These clouds were drifting rapidly to the east (left), the breeze at the ground level blowing towards the same direction. Ruskin wrote[1] long since of vapour "falling into ripples like sand." The general likeness is indeed striking, but the differences of detail are also noticeable, which is not to be wondered at, seeing that the cloud ripples are not the counterpart of the rippled sand, but of the whirling water between the sand ridges. How then shall we see the form of the aërial ripple mark where there is only blue sky? Simply by reproducing our photograph as a negative (Fig. 4). With this compare Fig. 5, an ordinary (positive) view of the wave-formed ripple mark of the strand, taken at Montrose, N.B., March 1900. Note the similarity of the sharp-topped ridges of still air, between the revolving cores where the clouds are, to the knife-edged ridges of the sand. But most remarkable of all is the precise correspondence of the confluence of ridges, wherever the wave-length of the ripple mark is about to change *per saltum* (for the wave-length of ripple mark increases in "multiple proportion," three ridges merging into two). And here our sky photographs are superior to, and throw light upon, our sand ripple mark photograph, for the latter had to be taken when the rippling action had ceased and the troughs were no longer filled with whirling water. Fig. 3, however, indicates what is going on where the ripple ridges are being merged, for the lights and shadows of the cloud indicate the activities of the working parts of the system. The rippled cloud here photographed, and consequently the true air ripples also, are symmetrical. This is not always the case; the clouds are often opaque (thick) at one edge and transparent (thin) at the other. In this case the form of the aërial ripple mark must be more like that of current mark, of æolian sand ripples and of tidal sand ripples. The likeness between cloud negative and sand ripple positive would be more striking but for the circumstance that we look up at the clouds and down at the sand. This makes the perspective different in the two. The real resemblance is best seen when separate prints are handled, one or other of which being inverted the perspective becomes similar in both.

Fig. 5.—Ripple mark of the strand. Photograph taken at Montrose, N.B., March 10, 1900.

[1] *Modern Painters*, vol. v. part 7, chap. i.

UNIVERSITY AND EDUCATIONAL INTELLIGENCE.

Cambridge.—A meeting of members of the Senate and others interested in the proposal to make some acknowledgment to Prof. Liveing for his valuable services to science and to the University will be held in the combination room of St. John's College on Saturday next, April 27, at 2.30 p.m.

Mr. Randolph Morgan, of Philadelphia, has given the sum of 200,000 dollars to the University of Pennsylvania for a new physical laboratory.

From the Catalogue of the University of Cincinnati, for 1900–1901, we see that the total endowment of the University amounts to 3,357,308 dollars, or nearly 700,000*l*. The latest large donation was in the year 1899, when Mr. David Sinton gave the University 100,000 dollars upon the condition that the income derived therefrom should be used in maintaining the Academic Department. The University has an observatory well equipped for carrying on astronomical work. The observatory is at the present time co-operating with the International Geodetic Association in the determination of the variation of latitude.

Lord Curzon, Viceroy of India, visited on Tuesday the Mahomedan Anglo-Oriental College, which was founded at Aligarh by Sir Syed Ahmad in 1875 with the view of affording Mahomedan youths an opportunity of gaining a first-class education under English professors. A marked success has since been obtained; the Nizam and all the Mahomedan notables affording liberal support. Alluding to the desire of Mr. Beck, the late principal, who devoted his life to the College, to expand the institution into a residential University, the *Times* reports Lord Curzon to have said that the project had reached the ears of the late Queen, who inquired most sympathetically about it. Lord Curzon warned his hearers that they would never get from a University consisting of little but examining boards that lofty ideal of education, the sustained purpose and the spirit of personal devotion associated with the historic Universities of England, and also produced in some measure by the ancient Universities of Islam.

The reality of the competition between School Board classes and Technical Institutions in some places is clearly exemplified by the following extract, from the latest Report of the Governing Body of the Goldsmiths' Institute, New Cross—in every respect an excellent institution, where thorough instruction is given in science and technology. "The Governors in their last Report drew attention to the decline in the number of students attending certain classes. This decline began in 1898 (down to that year the class entries had been uniformly progressive), and was mainly due to the extension of the Free Evening Continuation Schools of the London School Board, and particularly to certain special centres which have been opened close to the Institute. It will be sufficient on the present occasion to state that the same causes still operate to check the natural growth of the classes affected." Reference has been made (p. 553) to the recent decision in the Court of Appeal that School Boards cannot legally support classes of this character or science schools out of the rates, but it has not yet been decided whether this ruling will be accepted. The foregoing extract emphasises the necessity for finally deciding upon the scope or area of influence of the various educational authorities, and so giving our educational system an organic structure in which each part has clearly defined work to do.

A meeting of the Agricultural Education Committee was held on Tuesday, Sir William Hart Dyke presiding. The executive committee reported that the two subjects most urgently requiring